

# Face Mask Use and Persistence of Livestock-associated *Staphylococcus aureus* Nasal Carriage among Industrial Hog Operation Workers and Household Contacts, USA

Maya L. Nadimpalli,<sup>1</sup> Jill R. Stewart,<sup>1</sup> Elizabeth Pierce,<sup>1</sup> Nora Pisanic,<sup>2</sup> David C. Love,<sup>2,3</sup> Devon Hall,<sup>4</sup> Jesper Larsen,<sup>5</sup> Karen C. Carroll,<sup>6,7</sup> Tsigereda Tekle,<sup>7</sup> Trish M. Perl,<sup>8</sup> and Christopher D. Heaney<sup>2,9,10</sup>

<sup>1</sup>Department of Environmental Sciences and Engineering, UNC Gillings School of Global Public Health, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

<sup>2</sup>Department of Environmental Health and Engineering, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA

<sup>3</sup>Johns Hopkins Center for a Livable Future, Johns Hopkins University, Baltimore, Maryland, USA

<sup>4</sup>Rural Empowerment Association for Community Help, Warsaw, North Carolina, USA

<sup>5</sup>Department of Bacteria, Parasites and Fungi, Statens Serum Institut, Copenhagen, Denmark

<sup>6</sup>Division of Medical Microbiology, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA

<sup>7</sup>Microbiology Laboratory, Johns Hopkins Hospital, Baltimore, Maryland, USA

<sup>8</sup>Division of Infectious Diseases, Department of Medicine, University of Texas Southwestern Medical Center, Dallas, Texas, USA

<sup>9</sup>Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA

<sup>10</sup>Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA

**BACKGROUND:** Industrial hog operation (IHO) workers may persistently carry antibiotic-resistant, livestock-associated *Staphylococcus aureus* in their nasal cavities. It is unclear whether IHO work activities can alter IHO workers' and their household members' exposure to these bacteria.

**OBJECTIVE:** Our objective was to investigate the relationship of IHO work activities with persistence of antibiotic-resistant, livestock-associated *S. aureus* nasal carriage among IHO workers and their household members.

**METHODS:** At biweekly intervals over 4 months, IHO workers and their household members completed questionnaires and provided nasal swabs that were assessed for *S. aureus*, multidrug-resistant *S. aureus* (MDRSA), and livestock-associated markers (tetracycline resistance, *scn* absence, *spa* type). We examined the association between transient and habitual IHO work activities and *S. aureus* nasal carriage outcomes.

**RESULTS:** One hundred one IHO workers and 79 household members completed 1,456 study visits. Face mask use (each 25% increase) was associated with reduced odds of nasal carriage of MDRSA (odds ratio [OR]: 0.65 [95% confidence interval (CI): 0.46, 0.92], tetracycline-resistant *S. aureus* [OR = 0.74 (95% CI: 0.56, 0.97)], and *S. aureus* clonal complex (CC) 398/CC9 [OR = 0.77 (95% CI: 0.60, 0.99)]. IHO workers who ever (vs. never) gave pigs injections had higher odds of these outcomes. Among household members, living with an IHO worker who consistently ( $\geq 80\%$  of the time) versus sometimes or never used a face mask was associated with reduced odds of carrying *scn*-negative *S. aureus*, tetracycline-resistant *S. aureus*, and *S. aureus* CC398/CC9 (OR range: 0.12–0.20, all  $p < 0.05$ ), and consistent IHO worker coveralls use was associated with reduced odds of household member MDRSA carriage only. Living with an IHO worker who habitually had contact with  $\geq 4,000$  hogs (vs.  $< 4,000$ ) was associated with higher odds of household member livestock-associated *S. aureus* carriage.

**CONCLUSIONS:** Consistent face mask use was associated with reduced exposure to antibiotic-resistant, livestock-associated *S. aureus* among IHO workers and their household members. <https://doi.org/10.1289/EHP3453>

## Introduction

Hogs in the United States are primarily grown on industrial hog operations (IHOs), which are characterized by high densities of hogs grown in confined spaces (Macdonald and McBride 2009). To prevent disease outbreaks and until recently, to promote animal growth, hogs are routinely fed antibiotics (Love et al. 2011).

This practice can select for antibiotic resistance among bacteria that circulate among animals (Love et al. 2011). Since 2005, strains of antibiotic-resistant *Staphylococcus aureus*, including methicillin-resistant (MRSA) and multidrug-resistant *S. aureus* (MDRSA), have been detected among hogs grown on industrial operations in the United States, the European Union, and several Asian countries (Chuang and Huang 2015; Smith and Pearson 2011). These animal-associated strains can spread to occupationally exposed individuals, such as livestock operation workers and veterinarians, resulting in nasal colonization or infection (Benito et al. 2014; Wardyn et al. 2015, 2018). Between 20% and 60% of persons with frequent livestock contact have been found to persistently carry these bacteria in their noses (Köck et al. 2012; Nadimpalli et al. 2015; Sun et al. 2017; Verkade et al. 2013). Colonization with livestock-associated *S. aureus* can supplement or replace human-adapted *S. aureus* (Nadimpalli et al. 2015; Verkade et al. 2013), which persistently colonize the nasal cavities of approximately 20% of the general population (Kluytmans et al. 1997). In the European Union, *S. aureus* clonal complex (CC) 398 predominates among hogs and hog-exposed individuals, whereas CC9 appears to predominate in Asia (Chen and Huang 2014). In the United States, both clones have been described among hogs and hog-exposed individuals (Rinsky et al. 2013; Smith and Pearson 2011; Sun 2016).

Livestock-associated *S. aureus* can spread from nasally colonized individuals via human-to-human contact, albeit less effectively than non-livestock-associated strains (Bootsma et al. 2011; Cuny et al. 2015; Verkade et al. 2014). The sharing of livestock-associated *S. aureus* between IHO workers and their household

Address correspondence to C.D. Heaney, Department of Environmental Health and Engineering, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD 21205 USA. Telephone: (443) 287-4989. Email: [cheaney1@jhu.edu](mailto:cheaney1@jhu.edu)

Supplemental Material is available online (<https://doi.org/10.1289/EHP3453>).

D.H. is the program manager and co-founder of the Rural Empowerment Association for Community Help (REACH), a 501(c)(3) not-for-profit organization located in Duplin County, North Carolina. D.H. is a complainant in a Title VI administrative complaint against the North Carolina Department of Environmental Quality related to its statewide hog operation lagoon and spray field liquid waste management permitting system. There is no potential personal financial gain from this administrative complaint, which is not directly related to the research described in this manuscript and is not a lawsuit or litigation. The other authors declare that they have no actual or potential competing financial interests.

Received 2 February 2018; Revised 16 November 2018; Accepted 17 November 2018; Published 13 December 2018.

**Note to readers with disabilities:** EHP strives to ensure that all journal content is accessible to all readers. However, some figures and Supplemental Material published in EHP articles may not conform to 508 standards due to the complexity of the information being presented. If you need assistance accessing journal content, please contact [ehponline@niehs.nih.gov](mailto:ehponline@niehs.nih.gov). Our staff will work with you to assess and meet your accessibility needs within 3 working days.

contacts has been documented in several European countries (Garcia-Graells et al. 2013), as has a growing incidence of colonization in the broader community (Larsen et al. 2015). Individuals exposed to livestock-associated *S. aureus* are at risk of developing mild-to-severe infections, including skin and soft tissue infections (SSTIs), wound infections, pneumonia, endocarditis, osteomyelitis, and bacteremia (Smith et al. 2018; Smith and Wardyn 2015; Wardyn et al. 2018). In Denmark, most SSTIs caused by livestock-associated *S. aureus* occur among healthy IHO workers and their household members (Larsen et al. 2017). However, most bacteremia caused by livestock-associated strains are among elderly and immunocompromised persons who lack animal contact but live in rural communities where hog farms are concentrated (Larsen et al. 2017). Thus, from a public health perspective, it is critically important to prevent the off-farm transmission of livestock-associated *S. aureus* not only to protect the health of workers and their household contacts, but the health of community members who may be at higher risk for invasive staphylococcal disease.

The impact of IHO workers' occupational activities, including the use of personal protective equipment (PPE; e.g., gloves, coveralls, face mask, boots) on IHO workers' own nasal carriage of livestock-associated *S. aureus* remains unclear (MRSA expert group 2014). A 2014 cohort study of hog farmers in the Netherlands observed a protective effect of continuous face mask usage on persistent MRSA nasal carriage (van Cleef et al. 2014). However, among other studies conducted in Europe, most have found null or, paradoxically, a positive association between face mask and other PPE use and prevalence of *S. aureus* nasal carriage (Denis et al. 2009; Van Cleef et al. 2010; Wulf et al. 2008). Two cross-sectional studies examined the impact of PPE on workers' nasal carriage of livestock-associated *S. aureus* in the United States, and both have observed a potential protective effect. A 2008–2010 cross-sectional study of 148 hog operation workers in Iowa observed a decrease in MRSA ST398 nasal carriage among workers who reported use of coveralls and eye protection, although these associations were not statistically significant (Smith et al. 2013). In 2016, a cross-sectional study of 103 IHO workers in North Carolina (a baseline analysis of the cohort described here) found nasal colonization with *scn*-negative *S. aureus* (absence of *scn* indicates livestock adaptation) was less prevalent among workers who always used face masks versus those who never used them (Nadimpalli et al. 2016).

In the United States, workers at industrial food animal production operations may not always be provided with PPE by their employers, and their use of PPE may be inconsistent (Graham et al. 2008). Studies that characterize the relationship between transient (time-varying changes) and habitual (time-averaged) work activities, including on-the-job PPE use, and changes in nasal carriage of livestock-associated *S. aureus* among IHO workers in the United States are lacking. Further, as household members have not been included in the few repeated-measures studies conducted thus far (Nadimpalli et al. 2015; Sun et al. 2017), it remains unknown whether variability in IHO work activities, including PPE use, might impact their household members' nasal carriage of livestock-associated *S. aureus* over time.

In this study, we examined the temporal dynamics of *S. aureus* nasal carriage among IHO workers and their household contacts participating in a 4-month, repeated-measures cohort study in eastern North Carolina. Specifically, we examined *a*) the persistence of nasal carriage of *S. aureus* and related outcomes (antibiotic-resistant and livestock-associated strains) among IHO workers and their household contacts during study visits every 2 weeks (i.e., biweekly) over 4 months; *b*) whether IHO workers' transient (time-varying at biweekly intervals) occupational activities, including use of PPE, were related to their *S. aureus*

nasal carriage patterns; *c*) whether IHO workers' habitual (time-averaged across all biweekly visits) occupational activities, including use of PPE, were related to changes in biweekly *S. aureus* nasal carriage among both IHO workers and their household contacts; and *d*) potential *S. aureus* transmission events between IHO workers and their household contacts.

## Methods

Data were collected between October 2013 and June 2014 by community organizers from the Rural Empowerment Association for Community Help (REACH) with researchers from the Johns Hopkins Bloomberg School of Public Health (JHSPH) and the UNC Gillings School of Global Public Health at the University of North Carolina at Chapel Hill (UNC).

### Data Collection

Volunteers were recruited through snowball sampling by community organizers from REACH. Livestock workers who fit the following criteria were eligible to participate: worked at an IHO, defined as farming operations where high densities of hogs are raised in confinement with nontherapeutic and therapeutic antibiotic inputs; resided in North Carolina; could speak English or Spanish; and were at least 18 y of age. Up to three individuals living in the same household as an IHO worker were eligible to participate if they were at least 7 y of age and spoke English or Spanish. Individuals who reported current employment at an IHO were not eligible to enroll as household members, although they could enroll as additional IHO workers living in the same household. Before participating, adult participants provided written informed consent. Written parental permission and informed assent were collected for participants 7–17 y of age. The JHSPH institutional review board (IRB) approved this study (IRB00004608). The UNC NonBiomedical IRB approved reliance on the JHSPH IRB.

Participants responded to a baseline questionnaire at enrollment and up to eight questionnaires every 2 weeks (i.e., biweekly) during the 4 months after the baseline visit, each administered by a community organizer. The baseline questionnaire assessed demographic information, household-level characteristics, and habitual (time-invariant) activities that could be related to antibiotic-resistant *S. aureus* exposure. At each biweekly visit, participants recalled personal and occupational activities within each of the two 1-week periods since the prior study visit. Both questionnaire types were reviewed with REACH and its community organizers and with current and former IHO workers for comprehension prior to the start of the study. All REACH community organizers were trained on questionnaire data collection in order to ensure congruity between organizers in how questions were posed and interpreted (including in the case of surveys of Spanish-speaking participants).

Participants provided a self-collected BD BBL CultureSwab™ (BD Diagnostics) from both of their nares each time a baseline or biweekly study questionnaire was completed. Community organizers supervised participants' self-collection of nasal swabs.

**Detection of *S. aureus* and MRSA.** Swabs were stored at the REACH office at 4–8°C prior to transport, and analyzed within 17 d of collection (median = 6 d). Upon arrival, swabs were vortexed in phosphate buffered saline (PBS) and either processed immediately or diluted with an equivalent volume of tryptic soy broth with 40% glycerol (w/v) and stored at –80°C for later processing.

An aliquot of fresh or thawed PBS eluate was directly plated onto CHROMagar™ Staph aureus plates (BD) and incubated overnight at 37°C. Presumptive *S. aureus* colonies (distinguished by mauve color) were hand counted to determine the number of

colony forming units (CFUs) per nasal swab. If plating of the neat solution yielded colonies that were too numerous to count, serial dilutions from the remaining PBS eluate were plated on CHROMagar Staph aureus and incubated overnight at 37°C. Up to two colonies with *S. aureus* morphology were streaked to isolation on trypticase soy agar with 5% sheep erythrocytes (blood agar; Remel). Swabs without characteristic *S. aureus* growth following direct plating of PBS eluate were enriched overnight at 37°C in 10 mL Mueller-Hinton broth with 6.5% NaCl, streaked onto both Baird Parker and CHROMagar Staph aureus plates (Nadimpalli et al. 2013), and incubated at 37°C for 24 h. Up to two colonies with *S. aureus* morphology from either media were then streaked to isolation on blood agar. One presumptive *S. aureus* colony per swab was assessed for the presence of the staphylococcal protein A (*spa*) gene, the *lukS-PV* and *lukF-PV* genes encoding Panton-Valentine leukocidin (PVL), and the *scn*, *mecA*, and *mecC* genes, as previously described (Nadimpalli et al. 2016). Colonies positive for *spa* were determined to be *S. aureus*; isolates with *spa* and either *mecA* or *mecC* were classified as MRSA.

**Strain typing.** The *spa* typing was performed using the Ridom StaphType 2.2.1 software and the Ridom SpaServer (<http://spa.ridom.de/index.shtml>) (European Union Reference Laboratory for Antimicrobial Resistance 2009). In previous work, we have assigned *spa* types to putative CC398 or CC9 using studies that report both *spa* types and multi-locus sequence types (MLST) for livestock-associated *S. aureus* isolates (Hasman et al. 2010; Lozano et al. 2012; Price et al. 2012). However, a recent study of hogs and hog veterinarians in the United States reported that some *spa* types typically associated with CC9 (i.e., t337 and t3446) clustered with CC398 when MLST was performed (Sun 2016). Thus, we assigned *S. aureus spa* types as “putative CC398 or CC9” in this study, rather than to each CC uniquely.

**Assessment of antibiotic susceptibility.** One isolate from each *S. aureus*-positive nasal swab was assessed for susceptibility to 14 classes of antibiotics (see Table S1 for a listing of antibiotics used), using the Phoenix Automated Microbiology System (BD Diagnostic Systems). Breakpoints were based on Clinical Laboratory Standards Institute (CLSI) guidelines (CLSI 2013). *S. aureus* isolates resistant to three or more classes of antibiotics were classified as multidrug-resistant *S. aureus* (MDRSA).

**Indicators of livestock association.** No consensus marker exists for identification of livestock-associated versus human-associated *S. aureus*. We examined three common indicators of livestock association among *S. aureus* isolates: absence of *scn*, tetracycline resistance, and *spa* type. For the purpose of this study, *spa* types t034, t571, t5883, t12116, t2582, t4652, t011, t14151, t14157, t14158, t1446, t3423, t337, t1430, t3446, t8890, t14156, t1419, and t3270 were considered livestock-associated (Nadimpalli et al. 2015, 2016).

## Statistical Analysis

We examined two timescales of self-reported IHO work activities—*a*) transient, that is, time-varying exposures that could change at biweekly intervals, and *b*) habitual, that is, time-averaged across all biweekly visits—and their respective relation with biweekly changes in the presence or absence of participants’ *S. aureus* nasal carriage outcomes. For analyses involving transient IHO work activities, we used conditional fixed-effects logistic regression models to examine how changes in IHO workers’ exposures the week prior to nasal swabbing (e.g., hours worked, number of hogs contacted) were related to biweekly changes in the presence vs. absence of nasal carriage of *S. aureus*, MDRSA, and livestock-associated classifications (Allison 2005). We considered all exposures listed in Table S2. Additionally, we examined whether time-varying changes in reported dust levels, barn temperature, and malodor were

potential confounders of associations between changes in IHO workers’ PPE use the week prior to nasal swabbing and biweekly changes in their *S. aureus* nasal carriage outcomes (see Table S3). We did not examine whether changes in dust, barn temperature, and malodor were confounders of associations between IHO workers’ compulsory work activities (e.g., number of hogs contacted, giving pigs shots) and biweekly *S. aureus* nasal carriage outcomes because, based on prior knowledge, changes in barn conditions would have been unlikely to impact changes in compulsory work activities. Adjusted models were consistent with crude models [same direction and generally, same magnitude (see Table S3)], and thus only crude fixed-effects model results are presented.

For analyses involving habitual IHO work activities, we first calculated the within-worker average of a self-reported IHO work activity across all of a worker’s biweekly study visits during the 4 months of follow-up (see work activities listed in Table S2). We then categorized IHO workers into two habitual exposure groups for each work activity. For infrequent dichotomous work activities (e.g., pressure washed barns), IHO workers were categorized as “Ever” versus “Never” exposed over the 4-month period. For common dichotomous work activities (e.g., handled dead pigs) IHO workers were categorized as “Sometimes or never” (i.e., reported at  $\geq 0$  but  $< 80\%$  of completed biweekly visits) versus “Consistently” exposed (i.e., reported at  $\geq 80\%$  of completed biweekly visits). For continuous work activities reported as numbers (e.g., total number of hogs in contact with), categorical cutoffs were based on the median value of within-worker averages, rounded to one significant digit. For continuous work activities reported as percentages (i.e., PPE use), IHO workers were categorized as “Sometimes or never” users (i.e., reported using PPE  $< 80\%$  of the time, on average) versus “Consistent” users (i.e., reported using PPE  $\geq 80\%$  of the time, on average). PPE that  $\geq 90\%$  of workers consistently used over the 4-month period were not included in our subsequent analyses due to insufficient variability. Specifically, IHO workers’ habitual use of gloves (92% of participants were consistent users) and boots (97% of participants were consistent users) were not considered.

We used logistic regression models with generalized estimating equations and an exchangeable correlation matrix (to account for the nonindependence of observations within households) to estimate associations between IHO workers’ habitual occupational activities and biweekly changes in the presence or absence of nasal carriage of *S. aureus*-related outcomes. The same model format was used to estimate the relation of IHO workers’ habitual work activities with household members’ biweekly nasal carriage of *S. aureus*-related outcomes. For households with more than one IHO worker (51 households comprised both IHO workers and household participants; 14/51 included two IHO workers), we used the IHO worker in the household who had the most extreme habitual occupational exposure (e.g., lowest proportion of average face mask use, highest average number of hogs in contact with) to estimate associations with household members’ nasal carriage outcomes.

IHO workers and household members rarely carried MRSA; one IHO worker persistently carried MRSA over 4 months (1%), but no household member did (see Table S4). Thus, this outcome was not examined in statistical models.

Analyses were performed using SAS (version 9.4; SAS Institute, Inc.) and Stata (version 11.2; STAT Corp.). We defined statistical significance as  $p < 0.05$ .

## Results

### Study Population

One hundred eighty participants comprising 101 IHO workers (56%), 26 adult household members (14%), and 53 minors (30%)

enrolled in the cohort between October 2013 and June 2014 and completed at least 1/8 biweekly visits. Participants' characteristics are described in Table 1. These 180 participants belonged to 80 unique households, 51/80 of which included both IHO workers and household members participating in the cohort study. IHO workers' personal and occupational exposures that varied during the 4-month study period (e.g., number of hogs in contact with, application of pesticides) are described in Table S2.

A total of 1,588 nasal swabs were collected from participants. We excluded from further analysis all swabs that were frozen prior to processing (129/1,588) because a freezer malfunction during the study caused a reduction in *S. aureus* recovery. We also excluded from further analysis nasal swabs collected from participants who did not complete at least one of the eight biweekly visits (3/1,588) because the purpose of this study was to examine persistence of nasal carriage rather than prevalence. In total, 1,456 nasal swabs from 101 IHO workers (801 swabs), 26 adult household members (215 swabs), and 53 minors (440 swabs) were included (see Figure S1). Study participants contributed 8 of 9 possible swabs on average (minimum = 2, maximum = 9).

### Persistence of *S. aureus*-related Nasal Carriage Outcomes

IHO workers and household members differed in persistence of nasal carriage for most of the *S. aureus* outcomes we examined over the 4-month period (see Table S4). IHO workers were more likely to intermittently carry *scn*-negative *S. aureus* {prevalence ratio [PR] = 2.3 [95% confidence interval (CI): 1.4, 3.8]}, tetracycline-resistant *S. aureus* [PR = 2.8 (95% CI: 1.5, 5.2)], and

*S. aureus* putatively associated with either CC398 or CC9 [PR = 4.2 (95% CI: 1.9, 8.9)] compared with their household contacts. IHO workers were somewhat more likely than their household members to persistently carry these same outcomes, but except for *scn*-negative *S. aureus* [PR = 2.3 (95% CI: 1.0, 5.3)], these differences were not statistically significant ( $p > 0.05$  for each) (see Table S4). We did not detect PVL-encoding genes among *S. aureus* isolates.

All *S. aureus spa* types observed over the 4-month period are presented by participant type in Figure S2. Participants carried 14 unique *spa* types putatively associated with CC398 or CC9, most commonly t337 (83/1,456 biweekly study visits) and t034 (55/1,456 biweekly study visits). Six of 12 IHO workers who persistently carried putative *S. aureus* CC398 or CC9 over the 4-month period carried  $>1$  *spa* type; one IHO worker carried 4 (t1430, t571, t1937, and t337). However, all three household members who persistently carried putative *S. aureus* CC398 or CC9 carried the same *spa* type at each positive sampling point (t034).

In general, we detected significantly higher  $\log_{10}$  *S. aureus* CFU counts in swabs from persistent nasal carriers of *S. aureus* and *S. aureus* putatively associated with CC398 or CC9 compared with swabs from intermittent carriers of these outcomes (see Figure S5). We did not observe marked differences in average  $\log_{10}$  *S. aureus* CFU counts between IHO workers and household members who persistently carried either of these outcomes. However, only three household members were persistent carriers of *S. aureus* putatively associated with CC398 or CC9 and, therefore, relatively few nasal swabs ( $n = 19$ ) contributed to these calculations (see Table S4).

**Table 1.** Characteristics of 101 industrial hog operation (IHO) workers and 79 household members participating in a 4-month cohort study of *Staphylococcus aureus* nasal carriage in North Carolina, 2013–2014.

Characteristic	IHO workers	Adult household members	Minor household members
	<i>n</i> (%) <sup>a</sup>	<i>n</i> (%) <sup>a</sup>	<i>n</i> (%) <sup>a</sup>
Total N	101	26	53
Age (y; mean $\pm$ SD)	39 $\pm$ 11	38 $\pm$ 15	11 $\pm$ 3
Female	45 (45)	19 (73)	28 (53)
Race/ethnicity			
Hispanic	89 (88)	23 (88)	49 (92)
African American	12 (12)	2 (8)	3 (6)
White	0 (0)	1 (4)	1 (2)
Education			
K–5th grade	—	—	28 (53)
6–8th grade	—	—	16 (30)
9–11th grade	—	—	7 (13)
<High school	48 (48)	7 (27)	—
$\geq$ High school	53 (52)	19 (73)	—
Household size			
Single person	4 (4)	—	—
2 persons	8 (8)	4 (15)	1 (2)
$\geq 3$ persons	82 (81)	21 (81)	50 (94)
Missing	7	1	2
Household type <sup>b</sup>			
Worker(s) only	36 (36)	—	—
One worker and household member(s)	37 (37)	25 (96)	35 (66)
Two workers and household member(s)	28 (28)	1 (4)	18 (34)
Used antibiotics prior to enrollment			
$\leq 3$ months	7 (7)	3 (12)	2 (4)
$> 3$ months	90 (89)	23 (88)	50 (94)
Missing	4	0	1
Hospitalized prior to enrollment			
$\leq 3$ months	2 (2)	2 (8)	1 (2)
$> 3$ months	98 (97)	23 (88)	52 (98)
Missing	1	1	0

Note: Characteristics from participants who completed at least 1/8 biweekly study visits are reported. —, no data available; IHO, industrial hog operation; SD, standard deviation. Modified from Nadimpalli et al. (2016).

<sup>a</sup>Totals for each characteristic may not sum to the total number of participants due to missing information.

<sup>b</sup>Based on the types of participants who were enrolled. Additional IHO workers or household members who did not participate in the study may have been living in a participant's household.

## Time-varying IHO work activities and *S. aureus* Nasal Carriage Outcomes

Among the time-varying occupational activities we examined, only IHO workers' face mask use and recent pressure washing of barns were associated with changes in *S. aureus* nasal carriage outcomes (Table 2). For every 25% increase in the amount of time an IHO worker reported wearing a face mask, IHO workers had lower odds of nasal carriage of MDRSA [OR = 0.65 (95% CI: 0.46, 0.92)], tetracycline-resistant *S. aureus* [OR = 0.74 (95% CI: 0.56, 0.97)], and *S. aureus* putatively associated with clonal complex (CC) 398 or CC9 [OR = 0.77 (95% CI: 0.60, 0.99)]. IHO workers who reported pressure washing barns the week prior to nasal swabbing were less likely to carry *scn*-negative *S. aureus* [OR = 0.41 (95% CI: 0.19, 0.88)] and *S. aureus* putatively associated with CC398 or CC9 [OR = 0.38 (95% CI: 0.18, 0.84)] in their noses, compared with study visits in which they did not report pressure washing barns. Neither recent face mask use [OR = 0.93 (95% CI: 0.72, 1.21)] nor pressure washing of barns [OR = 1.33 (95% CI: 0.62, 2.88)] was associated with IHO workers' nasal carriage of *scn*-positive (human-associated) *S. aureus* (see Table S5).

Because most IHO workers' nasal swabs (683/801) were collected less than 24 h after their last work shift, we were unable to evaluate whether time since last work shift was associated with time-varying changes in *S. aureus* nasal carriage outcomes.

## Habitual IHO work activities and *S. aureus* Nasal Carriage Outcomes

IHO workers who reported consistently using a face mask over the 4-month period ( $\geq 80\%$  of the time, on average, vs.  $<80\%$  of the time) were less likely to carry MDRSA [OR = 0.31 (95% CI: 0.11, 0.83)], *scn*-negative *S. aureus* [OR = 0.50 (95% CI: 0.23, 1.10)], tetracycline-resistant *S. aureus* [OR = 0.32, 95% CI: 0.12, 0.88], and *S. aureus* putatively associated with CC398 or CC9 [OR = 0.51 (95% CI: 0.21, 1.20)] (Table 3; see also Figure S3). We also observed that IHO workers who reported ever giving pigs shots during the 4-month period (vs. never) were more likely to carry MDRSA [OR = 2.70 (95% CI: 1.00, 7.27)], *scn*-negative *S. aureus* [OR = 4.67 (95% CI: 1.77, 12.31)], tetracycline-resistant *S. aureus* [OR = 6.63, 95% CI: 2.22, 19.78], and *S. aureus* putatively associated with CC398 or CC9 [OR = 4.23 (95% CI: 1.65, 10.80)]. Reported shots included a variety of subcutaneous, intramuscular, and deep tissue injections such as steroidal and nonsteroidal injections to reduce inflammation, vaccinations against mycoplasma and influenza, iron injections to prevent anemia in young piglets, and antibiotic injections to prevent and treat bacterial diseases, including penicillin, lincosamide, oxytetracycline, and several proprietary mixes. Other occupational activities did not appear to be consistently associated with IHO workers' *S. aureus*-related nasal carriage outcomes (Table 3).

The household members of IHO worker(s) who consistently used face masks over the 4-month period ( $\geq 80\%$  of the time) were also less likely to carry *scn*-negative *S. aureus* [OR = 0.12 (95% CI: 0.04, 0.40)], tetracycline-resistant *S. aureus* [OR = 0.14 (95% CI: 0.04, 0.53)], and *S. aureus* putatively associated with CC398 or CC9 [OR = 0.20 (95% CI: 0.05, 0.81)], compared with the household members of IHO worker(s) who sometimes or never ( $<80\%$  of the time) wore face masks during the 4-month study (Table 4; see also Figure S4). Additionally, household members who lived with IHO worker(s) who consistently wore coveralls over the 4-month period ( $\geq 80\%$  of the time, on average) vs.  $<80\%$  of the time had lower prevalence of nasal carriage of MDRSA [OR = 0.27 (95% CI: 0.09, 0.85)]. The ORs were

similar for *scn*-negative *S. aureus* and tetracycline-resistant *S. aureus* but were based on smaller numbers of observations and were less precise (Table 4). Neither IHO workers' consistent use of face masks [OR = 1.57 (95% CI: 0.60, 4.10)] nor consistent use of coveralls [OR = 1.28 (95% CI: 0.48, 3.39)] was associated with household members' prevalence of nasal carriage of *scn*-positive (human-associated) *S. aureus* (see Table S6).

IHO workers' habitual work activities that involved direct contact with hogs were also associated with their household members' nasal carriage outcomes (Table 4). Household members were more likely to carry *scn*-negative *S. aureus* [OR = 13.09 (95% CI: 4.03, 42.56)], tetracycline-resistant *S. aureus* [OR = 7.92 (95% CI: 2.20, 28.52)], and *S. aureus* putatively associated with CC398 or CC9 [OR = 9.0 (95% CI: 1.62, 50.36)] if IHO worker(s) living in their household had contact with  $\geq 4,000$  hogs, on average, over the 4-month study period (vs.  $<4,000$  hogs). These associations were similar in direction and magnitude when examined within specific hog age groups (i.e., sows/farrow/wean/nursery vs. feeder/finish). However, the ORs were less precise due to smaller numbers. In households where IHO worker(s) consistently handled sick hogs over the 4-month period (reported handling sick hogs at  $\geq 80\%$  of biweekly study visits, vs.  $<80\%$ ), their household members were less likely to carry MDRSA [OR = 0.19 (95% CI: 0.07, 0.52)], *scn*-negative *S. aureus* [OR = 0.07 (95% CI: 0.01, 0.50)], and tetracycline-resistant *S. aureus* [OR = 0.10 (95% CI: 0.01, 0.75)]. However, for 10 of the 11 households in which this activity was consistently reported, IHO worker(s) living in the household also consistently wore a face mask ( $\geq 80\%$  of the time, on average). Thus, these protective associations may be a consequence of IHO workers' consistent face mask use during this work activity.

## Within-household concordance of *S. aureus* spa Types

Among 51 households comprising both IHO workers and household contacts, we completed 358 household visits at which both IHO workers and household members contributed nasal swabs. We detected the same *S. aureus* spa type among IHO workers and their household contacts in 21/51 households during 11% of these study visits (40/358) (see Table S7). The spa types t645 and t233, neither of which have previously been associated with livestock reservoirs, were the most frequently concordant spa types. Concordant *S. aureus* spa types carried by IHO workers and their household contacts shared at least one indicator of livestock association (absence of *scn*, tetracycline resistance, or spa type putatively associated with CC398 or CC9) during 4 of 358 study visits among 4 of 51 households.

## Discussion

In this longitudinal cohort study of IHO workers and their household contacts, we observed that increased face mask use among IHO workers was associated with a lower likelihood of nasal carriage of *scn*-negative *S. aureus*, tetracycline-resistant *S. aureus*, and *S. aureus* putatively associated with CC398 or CC9. In addition, the household members of IHO workers who consistently wore face masks ( $\geq 80\%$  of the time) had  $\sim 80$ – $90\%$  reduced odds of nasal carriage of these same outcomes. Conversely, IHO workers' face mask use was associated with neither their own nasal carriage nor their household members' nasal carriage of *scn*-positive (human-associated) *S. aureus*. Because exposure to livestock-associated *S. aureus* has been associated with infection among hog production workers and their household contacts (Nadimpalli et al. 2016; Smith et al. 2018; Smith and Wardyn 2015; Wardyn et al. 2018), as well as among elderly and immunocompromised persons who lack animal contact but live in

**Table 2.** Associations between 101 industrial hog operation (IHO) workers' time-varying (transient) occupational activities the week prior to biweekly nasal swabbing time points and changes in nasal carriage of multidrug-resistant and livestock-associated *Staphylococcus aureus* outcomes over 4 months, North Carolina, USA, 2013–2014.

Characteristic	Overall N = 801					IHO workers' nasal carriage outcomes at 801 biweekly study visits <sup>a</sup>					Putative <i>S. aureus</i> CC398 or CC9 N = 174				
	MDRSA N = 159					Tetracycline-resistant <i>S. aureus</i> N = 140					Putative <i>S. aureus</i> CC398 or CC9 N = 174				
	n (%)	Mean ± SD <sup>b</sup>	n (%)	Mean ± SD <sup>a</sup>	OR (95% CI)	n (%)	Mean ± SD <sup>a</sup>	n (%)	Mean ± SD <sup>a</sup>	OR (95% CI)	n (%)	Mean ± SD <sup>a</sup>	n (%)	Mean ± SD <sup>a</sup>	OR (95% CI)
No. of pigs in contact with <sup>b</sup>	27,627 ± 143,098	33,871 ± 105,499	0.88 (0.59, 1.31)	26,210 ± 91,918	0.91 (0.63, 1.30)	24,840 ± 58,763	0.67 (0.44, 1.02)	29,701 ± 98,101	0.85 (0.59, 1.23)						
No. of sows/farrow/ wean/nursery pigs in contact with <sup>b</sup>	8,546 ± 65,986	12,992 ± 85,059	1.00 (0.80, 1.25)	10,569 ± 74,446	1.04 (0.84, 1.29)	5,941 ± 20,333	0.90 (0.69, 1.18)	11,478 ± 79,736	0.97 (0.78, 1.21)						
Contact with feeder/ finish pigs	208 (26)	45 (28)	0.44 (0.14, 1.37)	47 (23)	0.39 (0.12, 1.25)	39 (28)	0.29 (0.08, 1.03)	46 (26)	0.62 (0.20, 1.96)						
Handled sick pigs	410 (51)	87 (55)	0.68 (0.30, 1.53)	116 (57)	0.72 (0.36, 1.45)	73 (52)	0.61 (0.27, 1.40)	99 (57)	0.73 (0.36, 1.50)						
Handled dead pigs	509 (64)	108 (68)	1.01 (0.43, 2.43)	147 (73)	0.80 (0.38, 1.72)	97 (69)	0.86 (0.35, 2.12)	127 (73)	1.02 (0.46, 2.28)						
Pressure washed barns	275 (34)	62 (39)	1.25 (0.52, 2.97)	67 (33)	0.41 (0.19, 0.88)	44 (31)	0.94 (0.40, 2.24)	55 (31)	0.38 (0.18, 0.84)						
Used pesticides	200 (25)	48 (30)	1.06 (0.50, 2.23)	53 (26)	0.62 (0.33, 1.15)	35 (25)	0.47 (0.22, 1.02)	48 (27)	0.64 (0.33, 1.25)						
Gave pigs shots	337 (42)	73 (46)	0.64 (0.28, 1.46)	99 (49)	0.66 (0.34, 1.29)	65 (46)	0.79 (0.36, 1.73)	84 (48)	0.82 (0.40, 1.66)						
Percentage of time used coversalls <sup>c</sup>	82 ± 37	75 ± 41	1.06 (0.77, 1.45)	75 ± 42	1.04 (0.81, 1.33)	77 ± 39	0.96 (0.73, 1.27)	74 ± 42	0.95 (0.74, 1.22)						
Percentage of time used face mask <sup>c</sup>	54 ± 46	32 ± 41	0.65 (0.46, 0.92)	40 ± 44	0.89 (0.71, 1.11)	33 ± 41	0.74 (0.56, 0.97)	37 ± 44	0.77 (0.60, 0.99)						
Percentage of time used gloves <sup>c</sup>	96 ± 18	95 ± 19	1.20 (0.74, 1.95)	96 ± 17	1.33 (0.80, 2.22)	97 ± 15	1.74 (0.86, 3.50)	96 ± 18	1.36 (0.86, 2.15)						
Percentage of time used boots <sup>c</sup>	99 ± 9	100 ± 0	—	100 ± 0	—	100 ± 0	—	100 ± 0	—						
Percentage of time used goggles/glasses <sup>c</sup>	31 ± 43	17 ± 31	0.99 (0.69, 1.43)	16 ± 31	1.10 (0.86, 1.41)	15 ± 29	0.82 (0.58, 1.17)	15 ± 30	0.97 (0.74, 1.27)						
Average no. of hours worked per week at IHO <sup>d</sup>	43 ± 11	45 ± 11	1.02 (0.71, 1.47)	45 ± 10	1.13 (0.78, 1.64)	44 ± 10	0.89 (0.59, 1.35)	45 ± 10	1.12 (0.78, 1.62)						

Note: Effect measures were generated using conditional fixed-effects logistic regression models. Fixed-effects models examine associations between within-person changes in an exposure and within-person changes in an outcome over time. —, no data available; CI, confidence interval; IHO, industrial hog operation; MDRSA, multidrug-resistant *S. aureus*; OR, odds ratio; SD, standard deviation.

<sup>a</sup>For binary exposures, the number of study visits for which the exposure was reported is provided as a percentage of all biweekly study visits, and as a percentage of the biweekly visits at which workers had specific nasal carriage outcomes (e.g., MDRSA). For continuous exposures, the mean and SD of the reported exposure is provided across all biweekly study visits and for biweekly visits at which participants had specific nasal carriage outcomes (e.g., MDRSA).

<sup>b</sup>Exposure was log-transformed for analysis.

<sup>c</sup>Examined in increments of 25%.

<sup>d</sup>Examined in increments of 10 h.

**Table 3.** Associations between 101 industrial hog operation (IHO) workers' habitual occupational activities over 4 months and biweekly nasal carriage of multidrug-resistant and livestock-associated *Staphylococcus aureus* outcomes, North Carolina, 2013–2014.

Characteristic	No. of biweekly study visits completed by IHO workers with exposure <sup>a</sup>	IHO workers' nasal carriage outcomes at 801 biweekly study visits							
		MDRSA N = 159		scn-negative <i>S. aureus</i> N = 202		Tetracycline-resistant <i>S. aureus</i> N = 140		Putative <i>S. aureus</i> CC398 or CC9 N = 174	
		n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)
Average no. of pigs in contact with <sup>b</sup>									
<4,000	418	67 (16)	Reference	96 (23)	Reference	66 (16)	Reference	87 (21)	Reference
≥4,000	383	92 (24)	1.45 (0.62, 3.38)	106 (28)	1.14 (0.57, 2.26)	74 (19)	1.10 (0.48, 2.53)	87 (23)	0.91 (0.43, 1.91)
Average no. of sows/farrow/ wean/nursery pigs in contact with <sup>b</sup>									
<2,000	427	59 (14)	Reference	90 (21)	Reference	61 (14)	Reference	81 (19)	Reference
≥2,000	374	100 (27)	2.09 (0.90, 4.86)	112 (30)	1.43 (0.71, 2.86)	79 (21)	1.44 (0.62, 3.33)	93 (25)	1.18 (0.56, 2.47)
Contact with feeder/finish pigs									
Never	431	69 (16)	Reference	110 (26)	Reference	61 (14)	Reference	90 (21)	Reference
Ever	370	90 (24)	1.51 (0.70, 3.27)	92 (25)	0.87 (0.45, 1.69)	79 (21)	1.54 (0.69, 3.44)	84 (23)	0.96 (0.48, 1.94)
Handled sick pigs									
Sometimes or never	681	142 (21)	Reference	171 (25)	Reference	123 (18)	Reference	152 (22)	Reference
Consistently	120	17 (14)	0.63 (0.17, 2.38)	31 (26)	1.08 (0.44, 2.62)	17 (14)	0.75 (0.26, 2.23)	22 (18)	0.82 (0.29, 2.32)
Handled dead pigs									
Sometimes or never	505	106 (21)	Reference	126 (25)	Reference	97 (19)	Reference	119 (24)	Reference
Consistently	294	53 (18)	0.80 (0.35, 1.80)	76 (25)	1.02 (0.46, 2.24)	43 (15)	0.70 (0.30, 1.63)	55 (19)	0.72 (0.31, 1.69)
Pressure washed barns									
Never	186	31 (17)	Reference	46 (25)	Reference	42 (23)	Reference	46 (25)	Reference
Ever	613	128 (21)	1.23 (0.46, 3.26)	156 (25)	0.95 (0.42, 2.11)	98 (16)	0.59 (0.24, 1.43)	128 (21)	0.71 (0.30, 1.66)
Used pesticides									
Never	186	22 (12)	Reference	32 (17)	Reference	29 (16)	Reference	24 (13)	Reference
Ever	611	137 (22)	1.86 (0.57, 6.05)	170 (28)	1.60 (0.59, 4.32)	111 (18)	1.02 (0.37, 2.81)	150 (25)	1.83 (0.62, 5.35)
Gave pigs shots									
Never	163	15 (9)	Reference	12 (7)	Reference	6 (4)	Reference	11 (7)	Reference
Ever	636	144 (23)	2.70 (1.00, 7.27)	190 (30)	4.67 (1.77, 12.31)	134 (21)	6.63 (2.22, 19.78)	163 (26)	4.23 (1.65, 10.80)
Frequency of overall use									
Sometimes or never	222	63 (28)	Reference	77 (35)	Reference	50 (23)	Reference	62 (28)	Reference
Consistently	579	96 (17)	0.53 (0.21, 1.29)	125 (22)	0.56 (0.28, 1.12)	90 (16)	0.68 (0.28, 1.66)	112 (19)	0.69 (0.32, 1.49)
Frequency of face mask use									
Sometimes or never	472	130 (28)	Reference	148 (31)	Reference	113 (24)	Reference	129 (27)	Reference
Consistently	329	29 (9)	0.31 (0.11, 0.83)	54 (16)	0.50 (0.23, 1.10)	27 (8)	0.32 (0.12, 0.88)	45 (14)	0.51 (0.21, 1.20)
Frequency of glasses/ goggles use									
Sometimes or never	659	147 (22)	Reference	192 (29)	Reference	129 (20)	Reference	164 (25)	Reference
Consistently	140	12 (9)	0.43 (0.10, 1.90)	10 (7)	0.25 (0.05, 1.12)	11 (8)	0.45 (0.09, 2.22)	10 (7)	0.32 (0.07, 1.42)
Average no. of hours worked per week at IHO <sup>b</sup>									
<40	199	28 (14)	Reference	38 (19)	Reference	27 (14)	Reference	31 (16)	Reference
≥40	602	131 (22)	1.24 (0.46, 3.29)	164 (27)	1.27 (0.48, 3.39)	113 (19)	1.14 (0.43, 3.06)	143 (24)	1.32 (0.49, 3.50)

Note: OR effect measures were estimated using logistic regression models with a generalized estimating equation and an exchangeable correlation matrix to account for the non-independence of observations within the same household. ORs were adjusted for the age and sex of IHO workers. CI, confidence interval; IHO, industrial hog operation; MDRSA, multidrug-resistant *S. aureus*; OR, odds ratio.

<sup>a</sup>IHO workers living in the household reported their occupational activities during the week prior at up to eight biweekly study visits. For dichotomous exposures expressed as “Sometimes or never” or “Consistently” (e.g., handled dead pigs), “Sometimes or never” refers to activities that an IHO worker reported at ≥0 but <80% of completed biweekly visits, and “Consistently” refers to activities reported at ≥80% of completed biweekly visits. For continuous exposures expressed as “Sometimes or never” or “Consistently” (e.g., percent time used face mask), “Sometimes or never” refers to activities a worker reported doing ≥0 but <80% of the time, on average, across all completed biweekly visits, and “Consistently” refers to activities a worker reported doing ≥80% of the time, on average, across all completed biweekly visits.

<sup>b</sup>Cutoff is the median value of the average numbers reported by workers over the 4-month period, rounded to one significant digit.

rural, hog-farm intensive communities (Larsen et al. 2017), it is critical to advance understanding of factors that might mitigate off-farm exposure to these stains.

By federal regulation, farm operators are required to provide respirators to workers exposed to harmful dusts, gases, smoke, or sprays; to provide instructions on their correct use; and to repair or replace respirators that are no longer protective (Occupational Safety and Health Standards: Personal Protective Equipment

2011). However, employers' compliance with policy may vary depending on the size and type of facility at which an IHO worker is employed (corporate, contract grower, or private) because small farms (i.e., ≤10 hired workers) are exempt from routine federal health and safety inspections (Occupational Safety and Health Administration 2018). Among 7,022 farms in North Carolina that reported employing nonseasonal labor in 2012, more than 90% (6,418/7,022) reported <10 hired workers

**Table 4.** Associations between 101 industrial hog operation (IHO) workers' habitual occupational activities over 4 months and biweekly nasal carriage of multidrug-resistant and livestock-associated *Staphylococcus aureus* outcomes by IHO workers' 79 adult and minor household members, North Carolina, 2013–2014.

Characteristic	79 household members' nasal carriage outcomes at 655 biweekly study visits							
	No. of biweekly study visits completed by household members with exposure	MDRSA N = 63		scn-negative <i>S. aureus</i> N = 46		Tetracycline-resistant <i>S. aureus</i> N = 34		Putative <i>S. aureus</i> CC398 or CC9 N = 26
		N = 655	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)
Exposure of IHO worker(s) living in the household <sup>a</sup>								
Average no. of pigs in contact with <sup>b</sup>								
<4,000	398	29 (7)	Reference	6 (2)	Reference	6 (2)	Reference	4 (1)
≥4,000	257	34 (13)	2.16 (0.70, 6.70)	40 (16)	13.09 (4.03, 42.56)	28 (11)	7.92 (2.20, 28.52)	22 (9)
Average no. of sows/farrow/wean/nursery pigs in contact with <sup>b</sup>								
<2,000	312	18 (6)	Reference	13 (4)	Reference	3 (1)	Reference	2 (1)
≥2,000	343	45 (13)	3.03 (0.90, 10.18)	33 (10)	2.50 (0.58, 10.70)	31 (9)	10.39 (2.12, 51.05)	24 (7)
Contact with feeder/finish pigs								
Never	481	31 (6)	Reference	27 (6)	Reference	25 (5)	Reference	18 (4)
Ever	174	32 (18)	4.39 (1.37, 14.09)	19 (11)	2.80 (0.67, 11.74)	9 (5)	1.41 (0.26, 7.56)	8 (5)
Handled sick pigs								
Sometimes or never	508	59 (12)	Reference	45 (9)	Reference	33 (7)	Reference	24 (5)
Consistently	147	4 (3)	0.19 (0.07, 0.52)	1 (1)	0.07 (0.01, 0.50)	1 (1)	0.10 (0.01, 0.75)	2 (1)
Handled dead pigs								
Sometimes or never	391	41 (10)	Reference	30 (8)	Reference	18 (5)	Reference	10 (3)
Consistently	264	22 (8)	0.64 (0.18, 2.31)	16 (6)	0.69 (0.15, 3.25)	16 (6)	1.29 (0.30, 5.58)	16 (6)
Pressure washed barns								
Never	142	31 (22)	Reference	14 (10)	Reference	5 (4)	Reference	3 (2)
Ever	513	32 (6)	0.20 (0.06, 0.61)	32 (6)	0.50 (0.12, 2.11)	29 (6)	1.23 (0.37, 4.04)	23 (4)
Used pesticides								
Never	123	22 (18)	Reference	21 (17)	Reference	11 (9)	Reference	8 (7)
Ever	523	41 (8)	0.34 (0.10, 1.19)	25 (5)	0.16 (0.05, 0.56)	23 (4)	0.25 (0.06, 1.06)	18 (3)
Gave pigs shots								
Never	79	10 (13)	Reference	6 (8)	Reference	6 (8)	Reference	6 (8)
Ever	576	53 (9)	0.42 (0.07, 2.44)	40 (7)	0.54 (0.06, 5.28)	28 (5)	0.30 (0.03, 2.70)	20 (3)
Frequency of coveralls use								
Sometimes or never	203	36 (18)	Reference	25 (12)	Reference	23 (11)	Reference	16 (8)
Consistently	452	27 (6)	0.27 (0.09, 0.85)	21 (5)	0.38 (0.11, 1.23)	11 (2)	0.24 (0.06, 1.05)	10 (2)
Frequency of face mask use								
Sometimes or never	365	43 (12)	Reference	42 (12)	Reference	31 (8)	Reference	23 (6)
Consistently	290	20 (7)	0.67 (0.19, 2.44)	4 (1)	0.12 (0.04, 0.40)	3 (1)	0.14 (0.04, 0.53)	3 (1)
Frequency of glasses/goggles use								
Sometimes or never	576	59 (10)	Reference	46 (8)	Reference	34 (6)	Reference	26 (6)
Consistently	79	4 (5)	0.78 (0.10, 6.28)	0	<sup>c</sup>	0	<sup>c</sup>	0 (1)
Average no. of hours worked per week at IHO <sup>b</sup>								
<40	130	16 (12)	Reference	2 (2)	Reference	2 (2)	Reference	0
≥40	525	47 (9)	0.68 (0.17, 2.76)	44 (8)	5.48 (1.30, 23.03)	32 (6)	3.18 (0.75, 13.57)	26 (5)

Note: OR effect measures were estimated using logistic regression models with a generalized estimating equation and an exchangeable correlation matrix to account for the non-independence of observations within the same household. ORs were adjusted for the age and sex of household members. CI, confidence interval; IHO, industrial hog operation; MDRSA, multidrug-resistant *S. aureus*; OR, odds ratio.

<sup>a</sup>IHO workers living in the household reported their occupational activities during the week prior to up to eight biweekly study visits. For dichotomous exposures expressed as "Sometimes or never" or "Consistently" (e.g., handled dead pigs), "Sometimes or never" refers to activities that an IHO worker reported at ≥0 but <80% of completed biweekly visits, and "Consistently" refers to activities reported at ≥80% of completed biweekly visits. For continuous exposures expressed as "Sometimes or never" or "Consistently" (e.g., percent time used face mask), "Sometimes or never" refers to activities a worker reported doing ≥0 but <80% of the time, on average, across all completed biweekly visits, and "Consistently" refers to activities a worker reported doing ≥80% of the time, on average, across all completed biweekly visits.

<sup>b</sup>Cutoff is the median value of the average numbers reported by workers over the 4-month period, rounded to one significant digit.

<sup>c</sup>OR could not be computed because at least one cell had a frequency of 0.

(National Agricultural Statistics Service 2012). Even if employees do provide respirators or other face protection, IHO workers have reported difficulties and discomfort while using them on the job (REACH, personal communication by Devon Hall). IHO workers have reported that face masks can be particularly uncomfortable to wear when barns are hot and humid (REACH, personal communication by Devon Hall); the summer temperatures in eastern North Carolina, where this study was conducted and where hog production in the United States is particularly concentrated, often exceed 32°C (90°F) with relative humidity >90% (National Agricultural Statistics Service 2012; State Climate Office of North Carolina 2018). Educational barriers may also exist concerning the potential protective benefits of routine face

mask use. Air is an important exposure pathway for acquisition of livestock-associated *S. aureus* nasal carriage inside IHOs (Angen et al. 2017; Bos et al. 2016; Davis et al. 2018; Feld et al. 2018; Schulz et al. 2012), and other studies have found that workers' airborne exposures can be significantly reduced through a combination of advanced hygienic measures, such as use of wet feed, negative ventilation, and using a mostly concrete floor (Basinas et al. 2013). PPE-based intervention trials have not been conducted in the United States to test efficacy of reductions in IHO workers' exposure to livestock-associated *S. aureus*.

Although we found evidence supporting within-household exchange of livestock-associated *S. aureus* (with face mask use mitigating exchange), we infrequently observed concordant *spa* types

between IHO workers and household contacts during the same study visit. This may suggest that sharing of livestock-associated *S. aureus* is indirect and time-staggered, occurring via surfaces that can become contaminated through touching or contact with IHO workers' PPE (Feld et al. 2018; Hatcher et al. 2016), for example, although we did not investigate these exposure pathways here. Overall, these findings suggest that livestock-associated *S. aureus* might be shared between IHO workers and their household environment—similar to other well-studied take-home occupational exposures such as agricultural pesticides (Curl et al. 2002).

Other time-varying work activities including recent pressure washing of barns appeared to decrease IHO workers' nasal carriage of *scn*-negative *S. aureus* and *S. aureus* putatively associated with CC398 or CC9. These findings were unexpected, considering increased aerosolization of dust particles during pressure washing should theoretically increase airborne exposure to livestock-associated *S. aureus*. At the time of this study (during 2013–2014), IHOs in eastern North Carolina were suffering from a pervasive porcine epidemic diarrhea virus epidemic (Schulz and Tonsor 2015). In our study, IHO workers reported pressure washing in order to “deep clean” confinement buildings after diseased and dead hogs had been removed. Thus, we hypothesize that reduced prevalence of IHO workers' nasal carriage of livestock-associated *S. aureus* was a result of reduced cumulative exposure to live animal waste and dust in the IHO environment, rather than the physical act of pressure washing barns. In models where we examined IHO workers' habitual work activities, we did not observe statistically significant associations between IHO workers' reports of ever pressure washing barns and prevalence of nasal carriage of livestock-associated *S. aureus*.

We did not identify transient IHO worker tasks involving direct animal contact that were associated with biweekly changes in IHO workers' nasal carriage of livestock-associated *S. aureus*. However, when we examined IHO workers' habitual work activities, we observed that ever versus never giving hogs shots (i.e., injections) was associated with IHO workers' increased odds of nasal carriage of MDRSA, *scn*-negative *S. aureus*, tetracycline-resistant *S. aureus*, and *S. aureus* putatively associated with CC398 or CC9. Giving hogs injections can be a high-contact activity that can require physical restraint of the animal and, particularly in the case of injections given behind the ear, such close contact may lead to workers' exposure to bioaerosols that a hog may produce through barking, breathing, or coughing. We also observed that IHO workers' habitual contact with  $\geq 4,000$  hogs (vs.  $< 4,000$  hogs) was associated with a higher prevalence of nasal carriage of *scn*-negative *S. aureus*, tetracycline-resistant *S. aureus*, and *S. aureus* putatively associated with CC398 or CC9 among their household contacts. The household members of IHO workers who consistently wore coveralls ( $> 80\%$  of the time) were also less likely to carry MDRSA, although a null association was observed for livestock-associated *S. aureus* outcomes. Although adjusted for age and sex, these models of habitual work activities were not adjusted for other potential time-invariant characteristics (e.g., underlying health conditions) due to the small sample size. Thus, these findings should be interpreted with caution and explored in future studies.

This study may have had a lower potential for recall bias compared with other U.S.-based longitudinal studies of livestock-associated *S. aureus* nasal carriage. Studies that rely on participants' recall of prior activities to classify exposure status may be subject to recall bias. However, IHO workers in this study were unaware of their nasal carriage status when reporting recent work activities. Thus, any exposure misclassification that may have occurred due to recall bias would be non-differential with respect to the outcome. Additionally, our focus on a short time frame

(i.e., the week preceding each biweekly study visit) for recall of exposures may have resulted in less recall bias compared with the month-long recall period used in two previous U.S.-based studies on this topic (Sun et al. 2017; Wardyn et al. 2015). Given prior literature describing the transiency of livestock-associated *S. aureus* nasal carriage (Graveland et al. 2011; Köck et al. 2012), this study's shorter time frame for recall of exposures may have been more biologically relevant for examining associations with nasal carriage status.

We achieved a relatively high level of participant retention and data completeness in this study, likely due to our community-based participatory research (CBPR) approach. The research questions we examined and the study design we employed were developed through coordinated efforts with REACH. This approach afforded a level of trust with study participants who may not have otherwise become engaged or been willing to participate in a research study, particularly one involving repeated data collection. In order to provide an additional level of protection of the privacy and confidentiality of study participants, we also obtained a certificate of confidentiality from the National Institutes of Health.

Overall, the distribution of persistent, intermittent, and noncarriers of *S. aureus* in this study population does not differ substantially from healthy populations in the United States (Muthukrishnan et al. 2013). Thirteen percent of workers in this study persistently carried *scn*-negative *S. aureus*, 9% persistently carried tetracycline-resistant *S. aureus*, and 12% persistently carried *S. aureus* putatively associated with CC398 or CC9 over the 4-month period. Persistent nasal carriage of livestock-associated *S. aureus* was lower in this study compared with previous reports among IHO workers and hog veterinarians in the United States (Nadimpalli et al. 2015; Sun et al. 2017) and Europe (Köck et al. 2012; van Cleef et al. 2014, 2011). A previous study we conducted in the same region found 46% of 22 IHO workers to persistently carry *S. aureus* with at least one indicator of livestock association over a 2-week period, including up to 96 h away from work (Nadimpalli et al. 2015). The distribution of persistent nasal carriers (vs. intermittent and noncarriers) may be more accurate in this study than our previous study (Nadimpalli et al. 2015) because we assessed *S. aureus* nasal carriage over a longer follow-up period; others have shown that individuals classified as persistent carriers during a short follow-up period (e.g., 2 weeks) are likely to be classified as intermittent carriers if followed for a longer period of time (e.g., 4 months) (VandenBergh et al. 1999). As in the general population, and as we have observed in previous studies (Nadimpalli et al. 2015; Rinsky et al. 2013), nasal colonization was dominated by methicillin-susceptible *S. aureus*, rather than MRSA.

Participants in this study lived in a region characterized by the highest density of industrial hog production in the United States and rapidly growing poultry production (National Agricultural Statistics Service 2012; Webb 2014). By venting animal barns and spraying animal waste on proximal fields, industrial food animal production facilities regularly emit *S. aureus* and other bioaerosols that could contaminate neighboring households (Davis et al. 2018; Gibbs et al. 2006; Green et al. 2006; Schulz et al. 2012). Thus, environmentally disseminated *S. aureus* could have contributed to IHO workers' and their household members' nasal carriage outcomes over the course of the 4-month study period. However, any impact of this environmental exposure pathway would have been non-differential with regard to the IHO work activities that we examined. For example, the proximity of an IHO worker's home to IHOs or other food animal production facilities should not be associated with his or her consistency of face mask use at work. Thus, proximity and density of industrial food animal production facilities are unlikely to be confounders of the results presented here. Nevertheless, future studies could examine whether living in proximity to IHO and spray fields is associated with livestock-

associated *S. aureus* nasal carriage and infection, particularly among community residents who do not have direct contact with livestock.

We did not ask IHO workers if they had previously worked at other types of industrial livestock operations (e.g., industrial poultry operations). Prior employment at industrial livestock operations might impact IHO workers' current work activities (e.g., as a result of injury, sensitization to allergens, or fear or reluctance to engage in certain high-contact activities). However, given that previous studies indicate that livestock-associated *S. aureus* present in IHO workers' noses is a result of frequent and ongoing contact with industrially raised animals (Graveland et al. 2011; Köck et al. 2012), we do not believe that prior work exposures were likely to influence IHO workers' *S. aureus* nasal carriage outcomes during our follow-up period.

Because most swabs were collected from IHO workers within 24 h of their last work shift (683/801), we were not able to investigate whether exposure to the IHO environment resulted in prolonged nasal colonization versus repeated transient contamination with MDRSA or livestock-associated *S. aureus* among IHO workers. Similarly, although we observed persistent colonization with MDRSA and livestock-associated *S. aureus* among some household contacts, this study was not designed to investigate whether adult and minor household members continued to carry these bacteria even when IHO worker(s) with whom they lived spent time away from work or after household contacts had time away from the home environment (which may potentially be contaminated with these bacteria). Surprisingly, household members who were persistent carriers of *S. aureus* putatively associated with CC398 or CC9 appeared to have similar numbers of *S. aureus* CFU in their noses, on average, as workers who persistently carried these outcomes. These findings were unexpected given that household members in this study had no direct contact with the IHO environment, the likely source of livestock-associated *S. aureus* (Davis et al. 2018). However, these findings were based on a small number of nasal swabs ( $n = 326$  because relatively few household members (10/79) ever carried *S. aureus* putatively associated with CC398 or CC9. Development of immunological biomarkers that could indicate persistent *S. aureus* colonization may be helpful in distinguishing between *S. aureus* colonization versus contamination in this population (Verkaik et al. 2009).

We did not collect on-site samples from hogs raised in IHOs or from the confinement barns in which IHO workers were employed. These samples would have increased our certainty that *S. aureus* with indicators of livestock association that were present in participants' noses were originating from the IHO environment. However, other hog sampling studies in the United States have documented a high prevalence of *S. aureus* with indicators of livestock association among hogs and described directional transmission to individuals in frequent contact with hogs (Smith et al. 2009; Sun et al. 2017). Further, a recent animal sampling study in eastern North Carolina indicates that hogs raised on IHOs are a source of *scn*-negative *S. aureus* and *S. aureus* putatively associated with CC398 or CC9 in this region (Davis et al. 2018). Future community-based studies could consider the use of spatial data collection (e.g., GPS logging) and personal sampling devices (Davis et al. 2018) to delineate IHO workers' exposures to *S. aureus* or other microbial hazards that are associated with time spent at work versus in the community.

Another limitation of this work is that only one *S. aureus* isolate was characterized per nasal swab. Analysis of only one *S. aureus* isolate may be insufficient to characterize the distribution of carriage of acquired genetic markers, such as virulence (e.g., *scn*) and resistance genes (e.g., multiple genes encoding tetracycline resistance) (Le et al. 2018). Thus, prevalence of nasal

carriage of these strain characteristics may be underestimated. For the same reason, we may have missed instances of strain concordance between IHO workers and their household contacts. Additionally, we did not ask IHO workers to report what type of face mask they used (e.g., cloth, surgical, N95 respirator). Future studies should investigate the heterogeneity of face mask use among IHO workers and whether this might impact *S. aureus* nasal carriage. Finally, as with previous studies we have conducted in this region of the United States (Nadimpalli et al. 2015; Rinsky et al. 2013), IHO workers and household members were recruited via snowball sampling, rather than via random sampling from an enumerated population (e.g., employee records). Thus, we are unable to generalize our findings to IHO workers or their household members in eastern North Carolina or the United States. Rather, these findings describe specific exposure–outcome associations among only those IHO workers and household members who were enrolled.

## Conclusions

Findings from this longitudinal study suggest that consistent face mask use may reduce nasal carriage of livestock-associated, antibiotic-resistant *S. aureus* in IHO workers' and their household members. Our findings add to a growing body of evidence that livestock-associated, antibiotic-resistant *S. aureus* may be directly or indirectly shared between IHO workers and their household contacts in the United States (Hatcher et al. 2016; Wardyn et al. 2018). Further, given emerging evidence that nasal colonization with livestock-associated *S. aureus* is a risk factor for developing skin and soft tissue infection (Nadimpalli et al. 2016; Wardyn et al. 2018), our finding that consistent PPE use (particularly face masks and coveralls) may limit occupational exposure suggests a need for future trials to test their preventative efficacy. Additional work is needed to evaluate and address potential impediments to PPE access and use among IHO workers in the United States.

## Acknowledgments

This study would not have been possible without a strong partnership between researchers and community-based organization members who have the trust of members of communities in areas where the density of industrial hog production is high. The authors thank the workers and their household members who participated in this study. The authors also acknowledge T. Le, S. Jiang, and C. Ifkovits (UNC Chapel Hill) and N. Kwiatkowski and T. Howard (Johns Hopkins Hospital Medical Microbiology Laboratory) for assistance with microbiology procedures and sample analysis. The authors dedicate this manuscript to the memory of Steve Wing, whose mentorship, guidance, and support of C.D.H. and other authors helped conceive the design and analytical framework for this cohort study.

Funding for this study was provided by National Institute for Occupational Safety and Health (NIOSH) grant K01OH010193; Johns Hopkins NIOSH Education and Research Center grant T42OH008428; a directed research award from the Johns Hopkins Center for a Livable Future; award 018HEA2013 from the Sherrilyn and Ken Fisher Center for Environmental Infectious Diseases Discovery Program at the Johns Hopkins University, School of Medicine, Department of Medicine, Division of Infectious Diseases; and National Science Foundation (NSF) grant 1316318 as part of the joint NSF–National Institutes of Health (NIH)–U.S. Department of Agriculture Ecology and Evolution of Infectious Diseases program. N.P. was supported by NIH/National Institute of Environmental Health Sciences (NIEHS) grant 5T32ES007141-30. M.N. was supported by a Royster Society fellowship and a U.S. Environmental Protection Agency Science to Achieve Results fellowship. D.C.L.

was supported by a gift from the GRACE Communications Foundation. J.L. was supported by the NIH/National Institute of Allergy and Infectious Diseases (NIAID) grant R01AI101371. C.D.H. was supported by NIOSH grant K01OH010193, E.W. “AI” Thrasher Award 10287, NIEHS grant R01ES026973, and NSF grant 1316318. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## References

- Allison PD. 2005. *Fixed effects regression methods for longitudinal data using SAS*. Cary, NC: SAS Institute.
- Angen Ø, Feld L, Larsen J, Rostgaard K, Skov R, Madsen AM, et al. 2017. Transmission of methicillin-resistant *Staphylococcus aureus* to human volunteers visiting a swine farm. *Appl Environ Microbiol* 83(23):e01489-17, PMID: 28970219, <https://doi.org/10.1128/AEM.01489-17>.
- Basinas I, Schlünssen V, Takai H, Heederik D, Omland Ø, Wouters IM, et al. 2013. Exposure to inhalable dust and endotoxin among Danish pig farmers affected by work tasks and stable characteristics. *Ann Occup Hyg* 57(8):1005–1019, PMID: 23792973, <https://doi.org/10.1093/annhyg/met029>.
- Benito D, Lozano C, Rezusta A, Ferrer I, Vasquez MA, Ceballos S, et al. 2014. Characterization of tetracycline and methicillin resistant *Staphylococcus aureus* strains in a Spanish hospital: is livestock-contact a risk factor in infections caused by MRSA CC398? *Int J Med Microbiol* 304(8):1226–1232, PMID: 25444568, <https://doi.org/10.1016/j.ijmm.2014.09.004>.
- Bootsma MCJ, Wassenberg MWM, Trapman P, Bonten MJM. 2011. The nosocomial transmission rate of animal-associated ST398 methicillin-resistant *Staphylococcus aureus*. *J R Soc Interface* 8(57):578–584, PMID: 20861037, <https://doi.org/10.1098/rsif.2010.0349>.
- Bos MEH, Verstaappen KM, van Cleef BAGL, Dohmen W, Dorado-García A, Graveland H, et al. 2016. Transmission through air as a possible route of exposure for MRSA. *J Expo Sci Environ Epidemiol* 26(3):263–269, PMID: 25515375, <https://doi.org/10.1038/jes.2014.85>.
- Chen C-J, Huang Y-C. 2014. New epidemiology of *Staphylococcus aureus* infection in Asia. *Clin Microbiol Infect* 20(7):605–623, PMID: 24888414, <https://doi.org/10.1111/1469-0691.12705>.
- Chuang Y-Y, Huang Y-C. 2015. Livestock-associated methicillin-resistant *Staphylococcus aureus* in Asia: an emerging issue? *Int J Antimicrob Agents* 45(4):334–340, PMID: 25593014, <https://doi.org/10.1016/j.ijantimicag.2014.12.007>.
- CLSI (Clinical and Laboratory Standards Institute). 2013. *M100-S23: Performance Standards for Antimicrobial Susceptibility Testing; Twenty-Third Informational Supplement*. Wayne, PA: CLSI.
- Cuny C, Wieler LH, Witte W. 2015. Livestock-associated MRSA: the impact on humans. *Antibiotics (Basel)* 4(4):521–543, PMID: 27025639, <https://doi.org/10.3390/antibiotics4040521>.
- Curl CL, Fenske RA, Kissel JC, Shirai JH, Moate TF, Griffith W, et al. 2002. Evaluation of take-home organophosphorus pesticide exposure among agricultural workers and their children. *Environ Health Perspect* 110(12):A787–A792, PMID: 12460819, <https://doi.org/10.1289/ehp.021100787>.
- Davis MF, Pisanic N, Rhodes SM, Brown A, Keller H, Nadimpalli M, et al. 2018. Occurrence of *Staphylococcus aureus* in swine and swine workplace environments on industrial and antibiotic-free hog operations in North Carolina, USA: a One Health pilot study. *Environ Res* 163:88–96, PMID: 29428885, <https://doi.org/10.1016/j.envres.2017.12.010>.
- Denis O, Suetens C, Hallin M, Catry B, Ramboer I, Dispas M, et al. 2009. Methicillin-resistant *Staphylococcus aureus* ST398 in swine farm personnel, Belgium. *Emerg Infect Dis* 15(7):1098–1101, PMID: 19624929, <https://doi.org/10.3201/eid1507.080652>.
- European Union Reference Laboratory for Antimicrobial Resistance. 2009. Protocol for *spa* Typing. [https://www.eurl-ar.eu/CustomerData/Files/Folders/21-protocols/289\\_7-protocols-for-spa-typing.pdf](https://www.eurl-ar.eu/CustomerData/Files/Folders/21-protocols/289_7-protocols-for-spa-typing.pdf) [accessed 25 November 2018].
- Feld L, Bay H, Angen Ø, Larsen AR, Madsen AM. 2018. Survival of LA-MRSA in dust from swine farms. *Ann Work Expo Health* 62(2):147–156, PMID: 29365048, <https://doi.org/10.1093/annweh/vwx108>.
- García-Graells C, van Cleef BAGL, Larsen J, Denis O, Skov R, Voss A. 2013. Dynamic of livestock-associated methicillin-resistant *Staphylococcus aureus* CC398 in pig farm households: a pilot study. *PLoS One* 8(5):e65512, PMID: 23741497, <https://doi.org/10.1371/journal.pone.0065512>.
- Gibbs SG, Green CF, Tarwater PM, Mota LC, Mena KD, Scarpino PV. 2006. Isolation of antibiotic-resistant bacteria from the air plume downwind of a swine confined or concentrated animal feeding operation. *Environ Health Perspect* 114(7):1032–1037, PMID: 16835055, <https://doi.org/10.1289/ehp.8910>.
- Graham JP, Leibler JH, Price LB, Otte JM, Pfeiffer DU, Tiensin T, et al. 2008. The animal-human interface and infectious disease in industrial food animal production: rethinking biosecurity and biocontainment. *Public Health Rep* 123(3):282–299, PMID: 19006971, <https://doi.org/10.1177/003335490812300309>.
- Graveland H, Wagenaar JA, Bergs K, Heesterbeek H, Heederik D. 2011. Persistence of livestock associated MRSA CC398 in humans is dependent on intensity of animal contact. *PLoS One* 6(2):e16830, PMID: 21347386, <https://doi.org/10.1371/journal.pone.0016830>.
- Green CF, Gibbs SG, Tarwater PM, Mota LC, Scarpino PV. 2006. Bacterial plume emanating from the air surrounding swine confinement operations. *J Occup Environ Hyg* 3(1):9–15, PMID: 16482973, <https://doi.org/10.1080/15459620500430615>.
- Hasman H, Moodley A, Guardabassi L, Stegger M, Skov RL, Aarestrup FM. 2010. *spa* type distribution in *Staphylococcus aureus* originating from pigs, cattle and poultry. *Vet Microbiol* 141(3–4):326–331, PMID: 19833458, <https://doi.org/10.1016/j.vetmic.2009.09.025>.
- Hatcher SM, Rhodes SM, Stewart JR, Silbergeld E, Pisanic N, Larsen J, et al. 2016. The prevalence of antibiotic-resistant *Staphylococcus aureus* nasal carriage among industrial hog operation workers, community residents, and children living in their households: North Carolina, USA. *Environ Health Perspect* 125(4):560–569, PMID: 28362266, <https://doi.org/10.1289/EHP35>.
- Kluytmans J, van Belkum A, Verbrugh H. 1997. Nasal carriage of *Staphylococcus aureus*: epidemiology, underlying mechanisms, and associated risks. *Clin Microbiol Rev* 10(3):505–520, PMID: 9227864, <https://doi.org/10.1128/CMR.10.3.505>.
- Köck R, Loth B, Köksal M, Schulte-Wülwer J, Harlizius J, Friedrich AW. 2012. Persistence of nasal colonization with livestock-associated methicillin-resistant *Staphylococcus aureus* in pig farmers after holidays from pig exposure. *Appl Environ Microbiol* 78(11):4046–4047, PMID: 22447613, <https://doi.org/10.1128/AEM.00212-12>.
- Larsen J, Petersen A, Larsen AR, Sieber RN, Stegger M, Koch A, et al. 2017. Emergence of livestock-associated methicillin-resistant *Staphylococcus aureus* bloodstream infections in Denmark. *Clin Infect Dis* 65(7):1072–1076, PMID: 28575216, <https://doi.org/10.1093/cid/cix504>.
- Larsen J, Petersen A, Sørum M, Stegger M, van Alphen L, Valentiner-Branth P, et al. 2015. Methicillin-resistant *Staphylococcus aureus* CC398 is an increasing cause of disease in people with no livestock contact in Denmark, 1999 to 2011. *Euro Surveill* 20(37):30021, PMID: 26535590, <https://doi.org/10.2807/1560-7917.ES.2015.20.37.30021>.
- Le T-T, Nadimpalli M, Wu J, Heaney CD, Stewart JR. 2018. Challenges in estimating characteristics of *Staphylococcus aureus* nasal carriage among humans enrolled in surveillance studies. *Front Public Heal* 6:163, PMID: 29911098, <https://doi.org/10.3389/fpubh.2018.00163>.
- Love DC, Davis MF, Bassett A, Gunther A, Nachman KE. 2011. Dose imprecision and resistance: free-choice medicated feeds in industrial food animal production in the United States. *Environ Health Perspect* 119(3):279–283, PMID: 21030337, <https://doi.org/10.1289/ehp.1002625>.
- Lozano C, Rezusta A, Gómez P, Gómez-Sanz E, Báez N, Martín-Saco G, et al. 2012. High prevalence of *spa* types associated with the clonal lineage CC398 among tetracycline-resistant methicillin-resistant *Staphylococcus aureus* strains in a Spanish hospital. *J Antimicrob Chemother* 67(2):330–334, PMID: 22127589, <https://doi.org/10.1093/jac/dkr497>.
- Macdonald JM, McBride WD. 2009. *The Transformation of U.S. Livestock Agriculture: Scale, Efficiency, and Risks*. Washington, DC: U.S. Department of Agriculture, Economic Research Service.
- MRSA Expert Group. 2014. MRSA Risk Assessment. [https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Dyresundhed/Rapport\\_fra\\_MRSA-ekspertgruppe%20EN.pdf](https://www.foedevarestyrelsen.dk/english/SiteCollectionDocuments/Dyresundhed/Rapport_fra_MRSA-ekspertgruppe%20EN.pdf) [accessed 25 November 2018].
- Muthukrishnan G, Lamers RP, Ellis A, Paramanandam V, Persaud AB, Tafur S, et al. 2013. Longitudinal genetic analyses of *Staphylococcus aureus* nasal carriage dynamics in a diverse population. *BMC Infect Dis* 13:221, PMID: 23679038, <https://doi.org/10.1186/1471-2334-13-221>.
- Nadimpalli M, Heaney C, Stewart JR. 2013. Identification of *Staphylococcus aureus* from enriched nasal swabs within 24 h is improved with use of multiple culture media. *J Med Microbiol* 62(pt 9):1365–1367, PMID: 23764742, <https://doi.org/10.1099/jmm.0.058248-0>.
- Nadimpalli M, Rinsky JL, Wing S, Hall D, Stewart J, Larsen J, et al. 2015. Persistence of livestock-associated antibiotic-resistant *Staphylococcus aureus* among industrial hog operation workers in North Carolina over 14 days. *Occup Environ Med* 72(2):90–99, PMID: 25200855, <https://doi.org/10.1136/oemed-2014-102095>.
- Nadimpalli M, Stewart JR, Pierce E, Pisanic N, Love DC, Hall D, et al. 2016. Livestock-associated, antibiotic-resistant *Staphylococcus aureus* nasal carriage and recent skin and soft tissue infection among industrial hog operation workers. *PLoS One* 11(11):e0165713, PMID: 27851746, <https://doi.org/10.1371/journal.pone.0165713>.
- National Agricultural Statistics Service. 2012. Census of Agriculture—2012 Census Volume 1, Chapter 1: State Level. [https://www.nass.usda.gov/Publications/AgCensus2012/Full\\_Report/Volume\\_1\\_Chapter\\_1\\_State\\_Level/](https://www.nass.usda.gov/Publications/AgCensus2012/Full_Report/Volume_1_Chapter_1_State_Level/) - State Data [accessed 25 November 2018].
- Occupational Safety and Health Administration. 2018. Enforcement Exemptions and Limitations under the Appropriations Act. Directive No. CPL 2-0.51J.

- Occupational Safety and Health Standards. 2011. Personal Protective Equipment. <https://www.osha.gov/SLTC/personalprotectiveequipment/standards.html> [accessed 25 November 2018].
- Price LB, Stegger M, Hasman H, Aziz M, Larsen J, Andersen PS, et al. 2012. *Staphylococcus aureus* CC398: host adaptation and emergence of methicillin resistance in livestock. *MBio* 3(1):e00305-11, PMID: 22354957, <https://doi.org/10.1128/mBio.00305-11>.
- Rinsky JL, Nadimpalli M, Wing S, Hall D, Baron D, Price LB, et al. 2013. Livestock-associated methicillin and multidrug resistant *Staphylococcus aureus* is present among industrial, not antibiotic-free livestock operation workers in North Carolina. *PLoS One* 8(7):e67641, PMID: 23844044, <https://doi.org/10.1371/journal.pone.0067641>.
- Schulz J, Friese A, Klees S, Tenhagen BA, Fetsch A, Rösler U, et al. 2012. Longitudinal study of the contamination of air and of soil surfaces in the vicinity of pig barns by livestock-associated methicillin-resistant *Staphylococcus aureus*. *Appl Environ Microbiol* 78(16):5666–5671, PMID: 22685139, <https://doi.org/10.1128/AEM.00550-12>.
- Schulz LL, Tonsor GT. 2015. Assessment of the economic impacts of porcine epidemic diarrhea virus in the United States. *J Anim Sci* 93(11):5111–5118, PMID: 26641031, <https://doi.org/10.2527/jas.2015-9136>.
- Smith TC, Gebreyes WA, Abley MJ, Harper AL, Forshey BM, Male MJ, et al. 2013. Methicillin-resistant *Staphylococcus aureus* in pigs and farm workers on conventional and antibiotic-free swine farms in the USA. *PLoS One* 8(5):e63704, PMID: 23667659, <https://doi.org/10.1371/journal.pone.0063704>.
- Smith TC, Hellwig EJ, Wardyn SE, Kates AE, Thapaliya D. 2018. Longitudinal case series of *Staphylococcus aureus* colonization and infection in two cohorts of rural Iowans. *Microb Drug Resist* 24(4):455–460, PMID: 29298107, <https://doi.org/10.1089/mdr.2017.0124>.
- Smith TC, Male MJ, Harper AL, Kroeger JS, Tinkler GP, Moritz ED, et al. 2009. Methicillin-resistant *Staphylococcus aureus* (MRSA) strain ST398 is present in midwestern U.S. swine and swine workers. *PLoS One* 4(1):e4258, PMID: 19145257, <https://doi.org/10.1371/journal.pone.0004258>.
- Smith TC, Pearson N. 2011. The emergence of *Staphylococcus aureus* ST398. *Vector Borne Zoonotic Dis* 11(4):327–339, PMID: 20925523, <https://doi.org/10.1089/vbz.2010.0072>.
- Smith TC, Wardyn SE. 2015. Human infections with *Staphylococcus aureus* CC398. *Curr Environ Health Rep* 2(1):41–51, PMID: 26231241, <https://doi.org/10.1007/s40572-014-0034-8>.
- State Climate Office of North Carolina. 2018. NC CRONOS Database (version 2.7.2). <https://climate.ncsu.edu/cronos> [accessed 25 November 2018].
- Sun J. 2016. Characterization of *Staphylococcus aureus* at the Human-Swine Interface [PhD Dissertation]. Minneapolis, MN:University of Minnesota.
- Sun J, Yang M, Sreevatsan S, Bender JB, Singer RS, Knutson TP, et al. 2017. Longitudinal study of *Staphylococcus aureus* colonization and infection in a cohort of swine veterinarians in the United States. *BMC Infect Dis* 17:690, PMID: 29052523, <https://doi.org/10.1186/s12879-017-2802-1>.
- van Cleef BAGL, Broens EM, Voss A, Huijsdens XW, Züchner L, van Benthem BHB, et al. 2010. High prevalence of nasal MRSA carriage in slaughterhouse workers in contact with live pigs in the Netherlands. *Epidemiol Infect* 138(5):756–763, PMID: 20141647, <https://doi.org/10.1017/S0950268810000245>.
- van Cleef BAGL, Graveland H, Haenen APJ, van de Giessen AW, Heederik D, Wagenaar JA, et al. 2011. Persistence of livestock-associated methicillin-resistant *Staphylococcus aureus* in field workers after short-term occupational exposure to pigs and veal calves. *J Clin Microbiol* 49(3):1030–1033, PMID: 21227986, <https://doi.org/10.1128/JCM.00493-10>.
- van Cleef BAGL, van Benthem BHB, Verkade EJM, van Rijen M, Kluytmans-van den Bergh MFQ, Schouls LM, et al. 2014. Dynamics of methicillin-resistant *Staphylococcus aureus* and methicillin-susceptible *Staphylococcus aureus* carriage in pig farmers: a prospective cohort study. *Clin Microbiol Infect* 20(10):O764–O771, PMID: 24494859, <https://doi.org/10.1111/1469-0691.12582>.
- VandenBergh MFQ, Yzerman EPF, van Belkum A, Boelens HAM, Sijmons M, Verbrugh HA. 1999. Follow-up of *Staphylococcus aureus* nasal carriage after 8 years: redefining the persistent carrier state. *J Clin Microbiol* 37(10):3133–3140, PMID: 10488166.
- Verkade E, Kluytmans-van den Bergh M, van Benthem B, van Cleef B, van Rijen M, Bosch T, et al. 2014. Transmission of methicillin-resistant *Staphylococcus aureus* CC398 from livestock veterinarians to their household members. *PLoS One* 9(7):e100823, PMID: 25062364, <https://doi.org/10.1371/journal.pone.0100823>.
- Verkade E, van Benthem B, Kluytmans-van den Bergh M, van Cleef B, van Rijen M, Bosch T, et al. 2013. Dynamics and determinants of *Staphylococcus aureus* carriage in livestock veterinarians: a prospective cohort study. *Clin Infect Dis* 57(2):e11–e17, PMID: 23588553, <https://doi.org/10.1093/cid/cit228>.
- Verkaik NJ, de Vogel CP, Boelens HA, Grumann D, Hoogenboezem T, Vink C, et al. 2009. Anti-staphylococcal humoral immune response in persistent nasal carriers and noncarriers of *Staphylococcus aureus*. *J Infect Dis* 199(5):625–632, PMID: 19199541, <https://doi.org/10.1086/596743>.
- Wardyn SE, Forshey BM, Farina SA, Kates AE, Nair R, Quick MK, et al. 2015. Swine farming is a risk factor for infection with and high prevalence of carriage of multidrug-resistant *Staphylococcus aureus*. *Clin Infect Dis* 61(1):59–66, PMID: 25931444, <https://doi.org/10.1093/cid/civ234>.
- Wardyn SE, Stegger M, Price LB, Smith TC. 2018. Whole-genome analysis of recurrent *Staphylococcus aureus* t571/ST398 infection in farmer, Iowa, USA. *Emerg Infect Dis* 24(1):153–154, PMID: 29260680, <https://doi.org/10.3201/eid2401.161184>.
- Webb D. 2014. Livestock, Dairy & Poultry—County Estimates: Turkeys. *Agricultural Statistics: North Carolina, 2015*. Publication No. 216. Raleigh, NC:U.S. Department of Agriculture; North Carolina Department of Agriculture, 35.
- Wulf MWH, Sørum M, van Nes A, Skov R, Melchers WJG, Klaassen CHW, et al. 2008. Prevalence of methicillin-resistant *Staphylococcus aureus* among veterinarians: an international study. *Clin Microbiol Infect* 14(1):29–34, PMID: 17986212, <https://doi.org/10.1111/j.1469-0691.2007.01873.x>.